VERIFICATION OF TRANSLATION

Re: PCT Patent Application PCT/CH00/00401

I, Alex H. Maitland of Hegaustrasse 10, CH-8200 Schaffhausen, Switzerland, am the translator of the documents attached and I state that the following is a true translation to the best of my knowledge and belief.

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11. 12. 2001

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Date

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No. EL 334671785US

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METHOD FOR SHAPING AN INITIAL PROFILE OR A SIMILAR WORKPIECE USING AN INTERNAL HIGH PRESSURE AND PROFILE THEREFOR

The invention relates to a process for forming an initial section or like component featuring a hollow interior to a final shape by means of high internal pressure in the sealed hollow interior using a medium that can flow, in particular forming until the final section comes into contact with the wall of a shape-determining space. Further, the invention also relates to a section with a space delimited by section walls, in which two section walls each determine a corner region of the cross-section, in particular an initial section for carrying out this process.

In the high-internal-pressure-forming (HIPF) process a hollow section is expanded by means of internal pressure. In addition, by means of at least one stem engaging the part in question, the hollow section may be displaced and widened, compressed or expanded.

The patent DE 35 32 499 C1 describes a device for hydraulic expansion of a length of pipe by using a plug-like cylindrical probe which can be introduced into the pipe and, using at least a pair of sealing rings spaced a distance apart, forms a circular space which is filled with compressive medium for the purpose of expanding the tube; each of the sealing rings is situated in a ring-shaped groove u-shaped in cross-section in the probe and at the start, on introducing the probe into the tube, has an outer diameter which at most is the same as the outer diameter of the probe. Before starting the expansion process, in order to seal the ring-shaped gap between the probe and the tube, compressive medium is introduced into the ring-shaped grooves via a feed pipe connected to the medium supply line and applies compressive force radially to the sealing rings. The feeding of the compressive medium to the ring-shaped space is performed solely by way of at least one of the grooves and is controlled by a sealing ring acting as a valve, which closes off an opening between the groove and the ring-shaped space until it has achieved its sealing function by elastic expansion. That groove is provided with at least one inclined slit at its edge neighbouring the ring-shaped space. If the pressure in the ring-shaped space between the two seals is increased, the wall of the tube begins to expand in this region.

This internal high pressure forming or hydroforming process is finding ever increasing application in the automobile industry as an economic means for manufacturing car body components. Mainly steel tubes are employed as starting material. The final contour of the component to be shaped this way is generally much more complicated than the simple

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circular cross-section of the starting material. As a rule the HIPF process results in regions which are much more heavily deformed than other regions and which are correspondingly thinner. If these regions are subjected to a high degree of loading in use, the initial sheet must be sufficiently thick; this however results in an unnecessary amount of material in the less heavily formed regions. This disadvantage is contrary to the requirement of obtaining the lowest possible weight in the component.

Recently aluminium alloys have been included along with steel as starting material for HIPF processes. As with steel there are manufacturing processes in which tubes of aluminium sheet are employed as starting material; alternatively, extruded aluminium sections may also be employed for that purpose. For economic reasons extruded steel sections do not come into question here. The use of extruded sections has the decisive advantage that the shape of the initial section is almost without limit.

HIPF processes using extruded sections are employed mainly to be able to produce high precision parts. To that end the present state of the art tends to make the shape of the initial section as close as possible to that of the final section in order to employ relatively small degrees of deformation in the HIPF-process. In particular with curved components that are to be bent in advance or where the section cross-sections feature sharp corners, this approach is usually not successful. Also attempts to keep the degree of deformation small generally results in its non-uniform distribution. As a result - and due to the pre-shaping from the bending process – spring-back effects are produced causing the desired precision to be achieved only in exceptional case using that process. Likewise as a rule, sharp corners which exhibit a large ratio of wall thickness to outer radius can not be filled out using this process.

In HIPF-processes using steel pipes it is normal to carry out pre-shaping prior to the actual shaping process (bending and HIPF) - this e.g. in order to arrive at a more favourable cross-section for bending or in order to make it even possible to place the part in the HIPF shaping tool.

In view of the above, the object of the present invention is to provide a specific cross-section of extruded section which achieves a favourable distribution of deformation in the HIPF-process; the elastic spring-back of the component after removal from the HIPF shaping tool should be minimised and dimensional accuracy achieved to the desired degree of precision.

That objective is achieved by way of the invention as described in the independent claims; the sub-claims provide favourable extensions. Also within the scope of the invention are all

combinations comprising at least two of the features described in the drawing and/or the claims.

In accordance with the invention, in order to shape-form the initial section featuring at least one corner region, the wall sections adjacent to the corner region are pre-shaped in a curved manner - as viewed in cross-section - counter to the direction of applied pressure, and subsequently re-shaped by applying the high internal pressure of the medium that can flow in the direction in which the pressure is applied, displacing the corner region; if there are at least two corner regions present, the wall lengths between the corner regions are accordingly pre-shaped counter to the direction in which the pressure is applied and re-shaped – likewise by applying the high internal pressure of the medium that can flow, displacing the corner regions in the direction in which the pressure is applied.

In practice the re-shaping will mainly concern angles that are almost right angles, whereby the section cross-sections need not have rectangular shaped contours. However, other sizes of angle can be re-shaped, in particular corners running to a peak with angles of less than 45°.

It has been found favourable to carry out the displacement of the corner region in the direction of the line bisecting the angle or its line of symmetry. In the initial section this corner region should also be of greater thickness.

The local degree of deformation can be created in the initial section in the form of oversizing with respect to the final contour of the final section, this by means of a doming – inward pointing curvature in the section cross-section. It is also possible to introduce the degree of deformation in the initial section in the form of undersizing with respect to the final contour of the final section.

Usefully, therefore, the requirements for precise light weight construction are met i.e. the initial section is designed in such a manner that at the end of the HIPF process the component exhibits an accumulation of material mainly in those places where, for reason of strength, this is required. In order to achieve the above mentioned goals:

- the local degree of deformation of the section wall is controlled by curvature in the cross-section and by lengths of section with local undersizing and, in this connection, the internal stress oriented in the longitudinal direction;

- section corners are made more pointed;

- those lengths of section which should undergo little or no deformation are made thicker;

- section cross-sections are curved in advance.

Controlling the local degree of deformation by means of dome-like, inwards pointing curvature of the cross-section, and section lengths that are undersized locally, is achieved using the following principle.

The inwards pointing curvature of the cross-section is important here; especially with regard to cross-sections whose section walls are curved in the final component it is emphasised that it depends on the relative curvature and not on the absolute curvature. This is so because in the end this determines whether the contour of the initial section - with respect to the final contour - exhibits oversizing or undersizing, through which the behaviour of the component in the described shape-forming process is controlled.

By doming or similar cross-sectional curvature it is possible to achieve local oversizing; in contrast to domed oversizing on the outside of the section, this doming does not cause any problem on placing the component into the mould or on closing the mould; in the HIPF process the oversizing causes local compression of the material in the direction along the periphery of the section. As a result of the constant volume of aluminium, internal compressive stresses are created in the longitudinal direction of the section, which on removing the component from the mould results in corresponding spring-back in the longitudinal direction. By providing lengths of section with local undersizing, the material is made to stretch in the peripheral direction of the section at these places during the HIPF process. Due to the above mentioned plastic constant volume of aluminium, tensile stresses are induced in the longitudinal direction of the section, which on removing the component from the mould, results in corresponding spring-back in the longitudinal direction.

A suitable distribution of stretching and compressive zones minimises the resultant overall spring-back, so that after the HIPF process the components obtained are accurate in shape.

In order to re-shape sharp corners at the same time avoiding excessive local degrees of deformation at the corners the following measures are taken:

- pronounced thickening of the section corners prevents irreversible bending at the start of the HIPF process;
- by providing dome-like curvature in the cross-section in the immediate vicinity of the thickened section corners it is possible to reduce, even completely eliminate the local stretching of the material necessary to re-shape small corner radii.

Within the scope of the invention is a hollow section featuring a space delimited by section walls where two section walls define each corner region of the section cross-section and at least one of the section walls adjacent to the corner region exhibits, as viewed in cross-section, a curved region. Preferred is a polygonal cross-section – in particular a triangle-shaped cross-section – the section walls of which exhibit an inward curved region between each of the corner regions; it is however also possible e.g. to provide only one single wall with a curved region. Usefully, the curved region of section wall should join up with corner regions at both ends. The cross-sectional shape of that curved region may be in the form of part of a circle or part of an ellipse, parabola shaped, hyperbola-like or have some other contour form.

It has been found favourable for such a bent region to exhibit a contour that is in the form of part of a circle, the arc length of which is defined as the distance between a pair of flanges that delimit the related corner regions. That distance is given by the length of section side wall less the lengths of the flanges in the related corner region – which, depending on the cross-sectional shape of the extrusion and the distribution of wall-thickness may also be unequal – and less the distance defined by the projection of the gap between the initial section and the contour of the shaping tool mould accommodating the component.

Usefully, the length of the flanges in the corner region of the initial section is three to four times the average wall thickness of the lengths of section walls adjacent to the corner region; the length of flange depends on the thickness of the section wall and on the angle these make at the corner region.

In the case of an initial section of cross-section in the form of an equilateral triangle that distance between the flanges should be e.g. about three times the length of the flange. In this case the height of doming, i.e. the distance between the curvature in the form of part of a circle and a straight line joining the flanges, should correspond approximately to the thickness of the section wall.

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On using extruded aluminium sections it is possible to avoid the work step involving pre-forming of the sections in that the initial section is manufactured in the desired favourable pre-bent shape. Apart from the savings associated with the pre-forming, at the same time a high degree of process reliability is achieved on bending or on closing the HIPF shaping tool.

Further advantages, features and details of the invention are revealed in the following description of preferred exemplified embodiments and with the aid of the drawing which shows schematically in:

Fig. 1: a part of a shaping tool shown in cross-section with optimally shaped section cross-section in a tool opening after an HIPF step;

Fig. 2: cross-section through an initial section according to the state-of-the-art within a too, contour – indicated by broken lines – before an HIPF step;

Fig. 3: the section in figure 2 after forming;

Fig. 4, 6: cross-section through an extruded initial section according to the invention and tool contour (shown enlarged in figure 6);

Fig. 5: the section in figure 4 after forming;

Fig. 7: a detailed sketch of part of figure 6;

Fig. 8: an extrusion frame shown in plan view;

Fig. 9: cross-section through figure 8 along line IX-IX;

Fig. 10: cross-section of the shaping tool employed to produce the final contour of the section frame;

Fig. 11: cross-section through an initial section for the section frame according to the state-of-the-art;

Fig. 12: cross-section through the initial section according to the invention;

Fig. 13: the initial section in figure 12 inside the shaping tool shown in cross-section;

Fig. 14: the cross-section of another section.

As shown in figure 1 a shaping tool 10 comprising a base part 11 and an upper part 12 features an interior space 14 with walls 15 in the form of an equilateral triangle with angles w of 60° and side lengths a; inside the tool 10 is a desired, ideal hollow section 18_i indicated by the inner contour 20 of its three walls 22; the outer contours 24 are coincident with the walls 15 of the tool 10.

In order to create a hollow section as the final section 18, an initial section – for example the initial section 16 shown in figure 2 – of narrower cross-section is introduced into the space 14. The outer contour 24 of this section 16 according to the state of the art in figure 2 corresponds to that of an equilateral triangle and stands an approximately equal distance t from the wall or wall contour 15. The initial section 16 is then expanded until it meets that wall contour 15 using the high internal pressure forming process (HIFP) in which – as shown in figure 3 - a fluid medium creates a high pressure in the direction shown by the arrows x in the interior 26 of the starting section 16.

After the HIFP-shaping step, the result is a hollow section 18 of larger cross-section; the middle region of the wall contour 24 of the section walls 22_a, as shown in figure 3, lie against the walls 15 of the shaping tool; towards the section corners, however, the corner regions 28 of the hollow section 18 maintain a distance i from the walls - the distance i increasing the closer to the corner and forming an angular space 29 those flanges tapers away from the corner of the wall contour 15 i.e. the corner is not filled out.

In order to avoid such undesirable shaping and to obtain, by means of HIFP-shaping, a final or hollow section 18a as shown in figure 5 that corresponds to the ideal hollow section 18_i, an initial section 16_n according to figure 4 is extruded with section walls 22_n that, in cross-section, are curved inwards as a part of a circle over a central region 30 of length e (indicated in figures 6, 7 by cross-hatched lines); the radius r of curvature K of the outer surface 32 of the curved region 30 corresponds approximately to length e ; in figure 6 for reason of clarity the curvature K is extended beyond the section wall 22_n. Running from the corners 19 of the section on both sides are linear wall sections of lengths f as flanges of the corner angle w of 120° or of the corner regions 28_n which are thicker than the wall thickness b. The distance between the corner regions 28_n - defined by the flanges 34 - defines the arc

length of the curvature K or the above mentioned length e and measures here approximately three times the length f of the flanges. The magnitude h of the crown formed by the curved outer contour or outer surface 32 of the section wall 22_n corresponds approximately to the wall thickness b, or is slightly larger. As a result of the radius of the levelling of the curved lengths 30 of section walls 22_n the high internal pressure pushes the described corner regions 28_n of angle w into the corresponding corner of the mould 14, with the result that the angular spaces 29 in the mould in the example shown in figure 3 is avoided. The corners are pushed in the directions determined by the corner middle lines N.

For reasons of clarity it should be pointed out that requirement the height h of the crown to be approximately the same as the thickness b of the wall applies only to the example chosen here; essential for the shape of the curvature K is its length or length of arc y (figure 7). The arc length y determines whether the length of section wall 22_n in question is greater or smaller than the length of sidewall a. If for example the length in question to be greater by an amount u (if it is smaller, then u is negative), then the arc length must be as follows

$$y = e + 2i_1 + u/2 \qquad (1)$$

where i_1 is a distance from the corner derived from the associated angle w and the local gap t according to the following relationship

$$i_1 = t * \tan(w/2). \qquad (2)$$

Further, taking into account the length of flange f:

$$e = a - 2(f + i_1). \qquad (3)$$

Depending on the type of curvature K, the height of crown h is a function of the length of arc y - indicated in figure 7. If K is a part of a circle, then - taking into account the angle of arc q formed by the radii r_1 of the curved region 30 – in addition to equation (1), the following equations may be used to determine the height of crown h:

$$h = r_1(1 - \cos(q/2)) \qquad (4)$$

$$e/2 = r_1 \sin(q/2) \qquad (5)$$

$$y = q\, r_1 \tag{6}$$

The height of crown h can be determined with the aid of an iteration method. Also, when designing a cross-section of an extrusion in practice using a CAD programme, the length of arc y of a curve is known and can be easily adjusted in order to arrive at the desired dimension.

The example discussed here is used in the following to demonstrate the filling out of sharp corner regions. The exact geometry of the part cross-section is not binding; it may also be a rectangular cross-section or a completely different - also irregular - geometry. In addition, as already mentioned, it is not necessary for the curvature K to be an arc of a circle; it is also possible to employ ellipses, parabolas, hyperbolas, splines or some other shape of curve.

A section frame 40 shown in the form of a sketch in figures 8, 9 is slightly curved along its length n of e.g. approximately 2000 mm and features a strut 41 at its side. At its ends 42 and in the middle region 43 the section frame 40 is welded to other components which are not shown here. In order to be able to employ a laser welding method, it is necessary to specify a tolerance of approx. ± 0.5 mm for the line of bending. Also the section frame 40 is made out of an aluminium extrusion which is first bent and then given its final shape in an HIPF process.

The contour 15 of the mould space 14a in the HIPF tool 10a in figure 10 corresponds exactly to the desired outer contour of the finished section frame 40. The bending process is chosen such that the slight curvature in the section frame 40 due to the change in cross-section resulting from the bending process can be neglected.

Up to now, as figure 11 shows, the cross-sectional shape of the initial section 38 is chosen to be as close as possible to the final shape; the upper section walls 45, 46 are curved outwards, the lower section wall 44 is straight and extended on one side by the above mentioned strut 41.

After bending, the component in question is introduced into the HIPF shaping tool 10a. By increasing the internal pressure, first the three section flanges or walls 44, 45, 46 come to rest on the wall contour 15. The corners with smaller radii are at first not changed in shape. On increas-ing the internal pressure further, the corner regions 48 are shape-formed. As a result of the friction between the tool 10a and the part 16, the tensile deformation in the direction of the periphery of the section which is necessary for filling out the corners is

restricted to the section corners 48 and the surrounding regions. Because of the constant volume of alumin-ium under plastic deformation, that deformation results in internal tensile stresses at the corners 48 in the longitudinal direction. The resulting moment referring to the main axis of bending A does not disappear as the internal tensile forces are mainly on the right side. On removing the part 38 from the tool 10a there is therefore elastic spring-back which, after the HIPF process causes the section frame 40 to exhibit a smaller curvature than that prescribed by the contour 15 of the tool wall. The required tolerance can therefore not be met.

The spring-back effects described above can be counteracted by designing the initial section 38_n as in figure 12. In order to achieve this, the moment around the main bending axis A caused by the internal stresses must be reduced or eliminated i.e. to the right of this main bending axis A one must induce mainly internal compressive forces instead of internal tensile forces or, left of the main bending axis one must induce mainly internal tensile forces. This is achieved by means of the cross-section of the initial section 38_n shown in figure 12 due to the following methods of design:

- The length of arc of the upper section wall 46_n remote from the strut is oversized with respect to the final contour with the result that in the HIPF process compression in the direction of the periphery occurs at this place and, as a consequence thereof, the desired internal compress-ive forces are induced in the longitudinal direction; the oversizing is in the form of doming towards the interior, in order to prevent deform-ation on closing the tool 10_a.

- The upper section wall 45_n close to the strut is undersized with respect to the final contour with the result that in the HIPF process stretching of the material occurs at this place in the direction of the periphery and, as a consequence thereof, the desired internal tensile forces are induced in the longitudinal direction.

- The base wall 44_n is - as viewed in cross-section - domed from the corner regions 48, this - as shown in figure 6 for a triangular section - in order to simplify the shape-forming of the corners 48_n.

In the HIPF process this initial section 38_n - in contrast to the state of the art design – the corner regions 48_n come to rest first on the tool contour 15. As a result of friction, the corner

regions 48_n of the part 38_n adhere to the tool. With the small wall thickness b normally used in HIPF applications even under good lubrication conditions ($\mu < 0.05$) most of the section surface adheres to the tool under tensile load.

On increasing the pressure further, the section walls 44_n, 45_n, 46_n, come to rest against the tool contour by plastically deforming, whereby the desired internal stresses are induced in the longitudinal direction of the section in order to prevent spring-back. The final section 50_n produced this way is indicated in figure 10 by only part of the contour.

The section 52 shown schematically in figure 14 is intended to show - as already mentioned – that the procedure described is not limited to triangular-shaped cross-sections. The double chamber section 52 exhibits on the left of a central wall 54 a chamber 56 with - between a base strip 57 and the central wall 54 – a curved side wall 59 and a chamber 60 on the right featuring a side wall 62, which runs from a roof strip 61 that runs parallel to and a distance from the base strip 57 and is made up of two lengths 62_a, 62_b that are inclined at angle to each other. This double-chamber section 52 feature four right angled corner regions 58. The curved regions in the walls 54, 57, 59, 61, 62 of the initial section are not shown in the drawing.

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